CHAPTER 1: BACKGROUND

HYDROLOGIC CYCLE

The first step in understanding stormwater management is to develop a feeling for the hydrologic cycle and how it is impacted by development. In simple terms, the hydrologic cycle involves the exchange of water between the earth and the atmosphere. Water is transported from the oceans to the atmosphere by evaporation, where it condenses and falls to the land in the form of precipitation. The water then makes its way back to the ocean, where the cycle is repeated. This is obviously a very simplistic explanation, as there are many sub-cycles (see figure 1.1) within the hydrologic cycle for the earth.

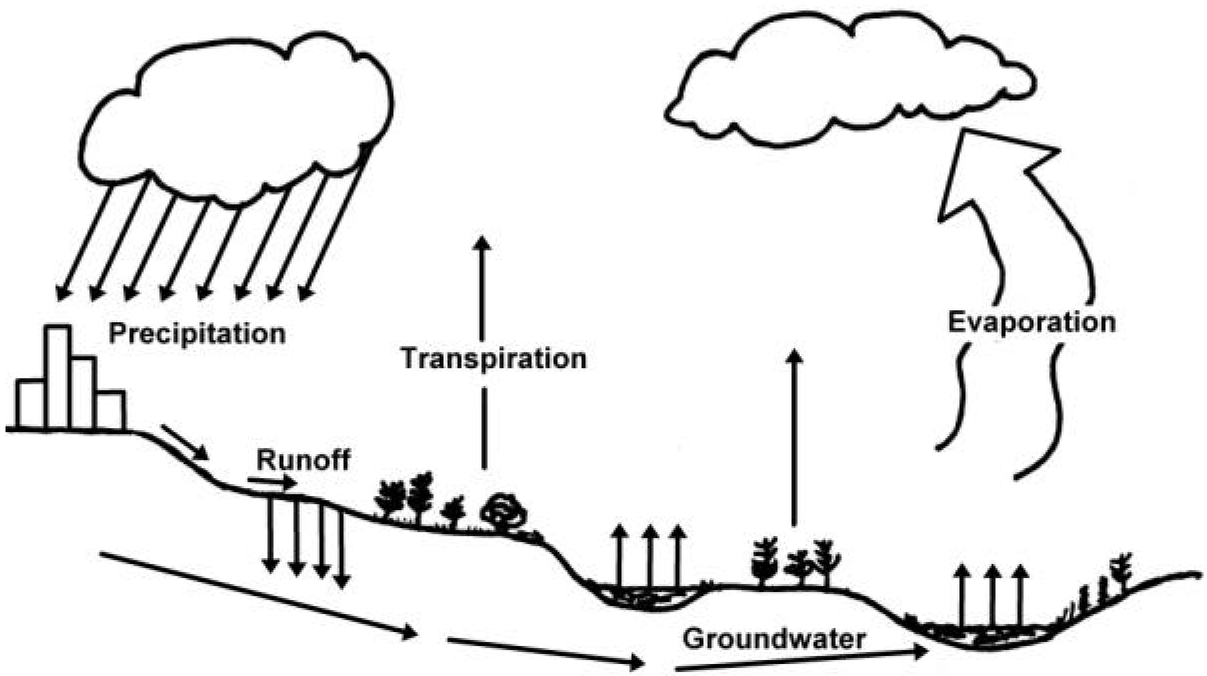

Figure 1.1 - Generalized Hydrologic Cycle

For stormwater management, we are primarily concerned about the portion of the hydrologic cycle that includes precipitation, infiltration, and runoff.

Whether in the form of rain or snow, **precipitation,** is the driving force behind the design of stormwater management facilities. The precipitation that occurs is either intercepted by vegetation (trees, plants, and etc.), evaporates, infiltrates into the ground, or results in runoff. Rainfall will be the primary focus of this guidebook.

Later on in the guidebook, we will discuss rainfall amounts and design suggestions for areas within Michigan. Obviously, snow can be a factor in estimating runoff volumes. Snow may not be immediately converted to runoff, as it is frozen and is "detained" until it can melt and runoff. However, when the snow does melt, it typically occurs in conjunction with a rainfall event which can compound the "runoff" problem.

Infiltration

The precipitation that infiltrates into the ground is either absorbed by the plants and soil or continues through the soil until it reaches the groundwater. The rate at which the water will infiltrate into the ground is dependent primarily upon three factors: soil type, soil moisture content, and land use.

One of the characteristics of soils is the ability to "absorb" moisture. A **soil type** such as sand has a high infiltration rate, while clay has a very low infiltration rate. Thus, all things being equal, a parcel with clay soil will produce higher runoff than if the soil is sand.

The **moisture content** of a soil also has considerable impact on the infiltration capacity of the soil. As an example, an area that has not received any rain in the last ten days will have a higher infiltration capacity than if it had received three inches of rain in the last two days. Thus, it is possible for an area that has not received any rain in the last couple of weeks to receive a "100-year rain" but not have a 100-year flood, since a large portion of the rainfall can be absorbed by the ground. Conversely, if a soil is saturated from recent rains, it may not take a 100-year rain to produce a "100-year flood".

Finally, the **land use** has a significant impact on the infiltration capacity of the soil. Residential, industrial, commercial developments, parking lots, and roads all result in the construction of **impervious** surfaces, such as pavement and rooftops. These impervious surfaces prevent water from infiltrating into the soil. If the water cannot infiltrate into the ground, runoff will result.

Even if impervious surfaces are not constructed, a change in land use can alter the runoff potential. Changing the land use from a meadow to straight row crops will increase the runoff potential. In this example, impervious surfaces were not added; however, changing the type and "density" of vegetation would impact the runoff volume.

Precipitation will become **runoff** when the infiltration capacity of the soil is exceeded by the intensity of the precipitation. In other words, "it comes down faster than it can soak in". As noted earlier, the amount of runoff will vary as the infiltration or land use is changed. It is this runoff that will be addressed in this guidebook.

IMPACTS OF URBANIZATION

The primary concerns in designing stormwater management facilities include the runoff volumes, the runoff peaks, and the pollutants carried by the runoff.

Runoff Volume

From figure 1.1, it can be seen that the runoff volume is a function of the amount of precipitation and infiltration. (During a precipitation event, evaporation and transpiration of water from plants to the atmosphere do not significantly affect the runoff.) It is apparent that the infiltration plays a key role in the quantity of runoff during a precipitation event.

As land is developed through the construction of buildings, roads, parking lots, and the like, infiltration capacity of a parcel of land is altered. The vegetation that allowed water to infiltrate into the soil is replaced by concrete and asphalt which are essentially impermeable. Instead of infiltrating into the soil, the water is forced to "runoff."

As an example, if a particular parcel is forested and has a sandy loam soil, the runoff from a 2-inch, 24-hour rain would be negligible. If that same parcel were a commercial area, such as a shopping mall or a central business district, a 2 –inch, 24 -hour rain would result in over 1.2 inches of runoff.

To get 1.2 inches of runoff from the parcel in a "natural" condition would require a 24 -hour rainfall of about 5.5 inches. In many areas of Michigan, a rainfall of 5.5 inches in 24 hours would have a frequency greater than a 100-year event.

Thus, if this parcel were to be developed from forest to a commercial area without regard to detention or retention, a rainfall that may occur 1 to 2 times in a year will have a runoff volume that is equal to a 100-year event prior to development. It is this increase in potential runoff volume that has raised the awareness of citizens in regard to stormwater management and the impact on downstream flooding.

Runoff Peaks

As runoff volumes are increased by urbanization and development, the potential for downstream flooding also increases. An increase of flooding problems will result in citizens demanding solutions to the flood problems. Typical solutions to flooding problems have been channelization, removing the "obstructions," and installation of larger-capacity storm drains. The primary goal has been to get the water out of the community and downstream as fast as possible. However, more often than not, improving the "systems" that transport the runoff, has simply passed the problem on to a downstream community. The channelization of streams and the installation of storm drains all result in the runoff reaching a location quicker. As figure 1.2 illustrates, the result of the "improvements" include:

- A flood peak that is larger than pre-development conditions.

- A flood peak that gets downstream quicker.

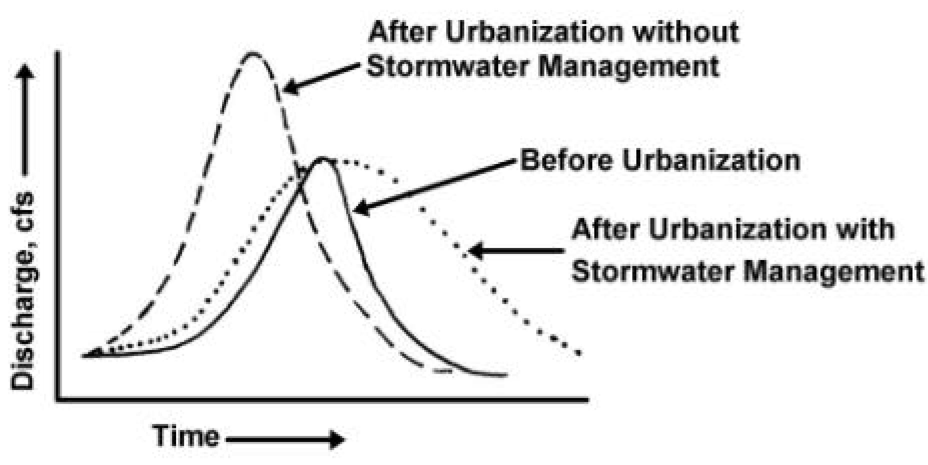

Figure 1.2 - Impact of Urbanization on Flood Peaks

Figure 1.2 also shows that proper stormwater management can limit the peak discharge on a stream to pre-development conditions by the controlling the time at which the runoff is allowed to travel downstream.

In addition to increasing the capacity of the transport system, urbanization will also tend to decrease the naturally occurring areas that provide storage of stormwater areas. Under natural conditions, a portion of the runoff will be captured in the natural storage areas, and will be **slowly** released back into the rivers and streams. The elimination of wetlands, depressions, or small ponds results in a greater runoff volume reaching the rivers and streams more quickly. As a result, flood peaks are increased, and the river levels will rise more rapidly. The elimination of natural storage areas can also lead to reduced base flow in streams during dry periods, which will degrade fish habitat.

Pollutants

As development takes place, there is an increase in the amount of materials that can be picked up by the stormwater runoff. Materials such as sediment, oils, toxic chemicals, fecal waste, and road salt all may be carried with the stormwater to a lake or stream. The construction of paved parking lots, streets with curbs and gutters, and storm sewers, result in little opportunity for the pollutants to settle out. The velocity of the transport systems keeps the pollutants in suspension until the runoff reaches a lake or a slower moving river. As a result, the water quality of the "receiving waters" will be diminished.

Thus, in addition to controlling the runoff volume and runoff peaks, an objective of stormwater management is also to improve the water **quality** of the stormwater runoff.

NON-POINT SOURCE POLLUTION

The sources that pollute a water-body can be classified into two groups: point source and non-point source pollution.

Point Source

As the name implies, point source pollution occurs at a specific location with a relatively consistent quality. The typical point source that is thought of as an example is an outlet pipe from an industrial complex, or a wastewater treatment plant.

Non-point Source

Non-point source pollution differs from point source in several ways:

1. It is not possible to identify one particular source. The pollution is occurring at locations scattered throughout the drainage basin.

2. The pollution is transported in a wide range of flows, with the majority of the pollutant transport occurring during runoff events due to a rainfall or snowmelt.

3. The quality of the runoff varies considerably during an event.

Non-point source pollution occurs in both urban **and** rural areas. In rural areas, non-point source pollution can result from construction-site erosion, agricultural activities (pesticides, herbicides, animal waste, and erosion), and natural erosion.

Best Management Practices

In 1972, the Federal Clean Water Act was amended to require permits for all point source discharges of pollutants to the waters of the United States. Throughout the 1970's, the primary focus of pollution control was the control of point source pollution. In the last 15 to 20 years there has been an increased awareness in non-point source pollution. Due to the nature of non-point source pollution, it became evident that it was not technically and economically feasible to eliminate **all** non-point source pollution. The term "best management practices" or **BMP** became popular. The U.S. Environmental Protection Agency defines BMPs as a practice or combination of practices that are effective, practicable means of preventing or reducing the amount of pollution generated by non-point sources.

BMPs can be divided into four categories, by identifying the methods which reduce the pollutant level of runoff discharging into a surface water body.

1. **Detention** - Water is temporarily stored before it discharges directly into a surface-water body. While the water is detained, the pollutant concentration can be reduced, as suspended solids and some pollutants settle out.

2. **Retention** (infiltration) - Water flows directly into the basin, and is not released. Water will leave the basin through infiltration and evaporation.

3. **Vegetated Swales & Strips** - The vegetation acts as a filter as it collects sedimentation and other pollutants. Water is also able to infiltrate as it is being transported by vegetated swales to a surface water body. The swales may be designed to "absorb" a given runoff condition, or it may be necessary to install a berm or "block" to detain the flow.

4. **Other Practices** - <u>Reduce accumulated pollutants</u> available to be picked-up by runoff. This may include sweeping parking lots and streets, catch-basin cleaning, erosion control enforcement, and infiltration of runoff from driveways and roofs. <u>Regulate the amount of impervious area</u> permitted through the use of zoning and ordinances. <u>Eliminate inappropriate discharges</u> to drains and storm sewers, such as sanitary or industrial sewage.

BMP methods are selected based on the water quality needs along with cost, drainage area, land use, soil, and topography. Using BMP, the stormwater management practices that are selected achieve the water quality needs in the most effective manner.

By incorporating several Best Management Practices, additional water quality benefits will be obtained, as opposed to relying on a single practice, such as the construction of a regional extended detention basin. A detention facility may be only a portion of the total BMP system, which may include:

a) Directing the runoff from downspouts and parking lots to vegetated swales or vegetated strips, instead of discharging directly to a stream.

b) Instituting and enforcing soil erosion control policies, including requiring a vegetated strip between cultivated land and a watercourse.

c) Instituting a policy of regular stormwater system maintenance, including street sweeping and cleaning catch basins; detecting and eliminating inappropriate hook-ups to storm drains.

d) Educating the public in the use of fertilizers, herbicides, and pesticides; in how to properly dispose of oils, paints, chemicals, and other waste/trash; and for the need for vegetated strips and wetland areas along lakes and streams.

Figure 1.3 indicates the "structural" type of BMP that would be feasible for given types of restrictions at a particular site. Later chapters will further discuss the restrictions and design guidelines.

	Soil Type								Drainage Area Acres		
BMP Type	Sandy-Loam	Loam	Silt-Loam	Silty Clay-Loam	High Water Table	High Sediment Input	Thermal Impacts	Limited Space	<5	5-20	20-100
Extended Detention	F	F	F	F	F	M	F	N	N	M	F
Wet Pond	M	F	F	F	F	M	N	N	N	M	F
Infiltration Basin	F	F	M	N	N	N	F	M	M	F	M
Grassed Swale	F	F	M	M	N	N	F	F	F	M	N
Filter Strip	F	F	F	M	M	N	F	F	F	M	N
Infiltration rate (in./hr.)	1.02	0.52	0.27	0.06							

Legend:
- F Feasible
- M Marginal - requires careful planning
- N Not Recommended

Figure 1.3 - Restrictions on BMPs*

*(Best Management Practices)

Source: References 10 & 38

Pollutants & Sources

There is large variety of pollutants that may be present in stormwater management, depending on the land use within the drainage basin. Following is a listing of some of the pollutants that are commonly found in stormwater runoff.

Sediment and Suspended solids: Sediments and other suspended solids account for the greatest amount of pollutants carried by stormwater runoff. Sediments can clog the gills of fish, cover spawning areas, harmfully affect other aquatic life, and reduce the flow-carrying capacity of the watercourse. The sediments may carry heavy metals and other contaminants.

The suspended solids can come from a wide range of sources including any activity that disturbs the land surface, such as clearing and grading activities, agricultural activities, and residential activities. Sediment will also occur from streets and road, and will occur naturally in the form of stream-bank erosion.

Heavy Metals: These pollutants include primarily copper, lead, zinc, and cadmium. Such metals can have a toxic impact on the aquatic life, and can contaminate the drinking water supply. The heavy metal pollutants can result from corrosion of metals, wood preservatives, algicides, paints, and electroplating. The metals are "picked up" by runoff from a variety of urban locations.

Oil and Grease: This category includes various hydrocarbon compounds, such as gasoline, oil, grease, and asphalt. The automobile is a major contributor of this pollutant. These pollutants will be picked up primarily from run-off from parking lots and streets.

Nutrients: The addition of phosphorus and nitrogen to the stormwater can result in increase growth of algae, odors, and decreased oxygen levels in the receiving waters. Such nutrient problems are particularly noticeable in detention ponds that have a detention time of greater than two weeks.

The nutrients typically come from sewage, and fertilizers used at homes, parks, golf courses, and in agriculture. In some areas, there are problems with sewers illegally connected to storm drains.

Fecal Coliform Bacteria: Bacteria are typically present in stormwater runoff. The bacteria may be a result of sanitary sewer overload, animal waste, or other sources that have not been identified. The introduction of bacteria into a receiving water body can make the water unfit for recreation and human use.

Oxygen Demand: Oxygen demand is a result of the decomposition of organic materials. If the depletion of dissolved oxygen is a concern to the receiving waters, it may be necessary to treat stormwater runoff with advanced wastewater treatment.

Other pollutants: There are many other pollutants, such as pesticides, chemical solvents, and phenols that may be found in stormwater runoff, but they are usually at very low concentrations.

"First Flush"

Most automobile drivers are aware that roads are the "slipperiest" after the first few minutes of a rainstorm. It is in those first few minutes that oil, grease, lead, and other pollutants that have accumulated on the pavement are picked up by the water on the roadway, and transported to storm drains or roadside ditches.

Stormwater runoff will result in concentrated pollutants being loaded into the storm -drains and receiving waters. As the rain continues, there are fewer pollutants available to be carried by the runoff, and thus the pollutant concentration becomes lower. Figure 1.4 shows a typical plot of pollutant concentration versus time. The sharp rise in the plot has been termed the "**first-flush**".

Some studies have yielded results which dispute the first flush theory. However, water quality measures that capture the first one-half inch of runoff would capture a high percentage of the runoff events that occur in Michigan. As a result, it is possible to capture a high percentage of the pollutants by retaining the first one-half inch of runoff.

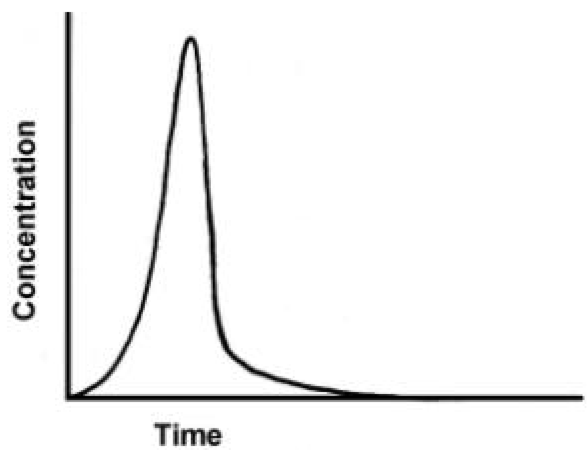

Figure 1.4 - Plot of Pollutant Concentration versus Time

In essence, most of the pollutants that have accumulated within the drainage basin since the last rain are "flushed" into the stormwater system in a very concentrated form. It is this initial pollutant loading that should be the prime concern of any stormwater management design. The design considerations will be discussed later on in the guidebook.